Control of knee joint motion in a dynamic knee rig

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1 Introduction

The biomechanics of the knee joint have been a focus of extensive research with a twofold reason [1]. Firstly, knee injuries account for 15 to 50% of all sports injuries and secondly, there is a considerable aging in the population which coincides with a high number of knee injuries caused by wear. Total knee replacement, i.e. replacing the knee by a prosthesis, is a common used treatment. To test the performance of newly designed prostheses, the orthopedic surgeons can use a knee rig where natural movements are imposed on the prosthesis. Controlling the motions and forces applied is not an easy task to do. Designing a control strategy for this application is the main focus of this research.

2 System description

The dynamic knee rig is shown in the left part of figure 1 and consists of 3 linear actuators: one which mimics the quadriceps (B) and two on the ankle joint (A and C) which mimic the resulting forces of the hamstrings and the rectus femoris which flexes the thigh at the hip. Both mechanical knees and cadaver knees can be placed in the knee rig in order to evaluate prosthetics. The system is an unstable multi-variable with 3 inputs, i.e. the 3 voltages to the linear actuators and 3 outputs: the x- (horizontal) and y- position (vertical) of the ankle and the quadriceps force.

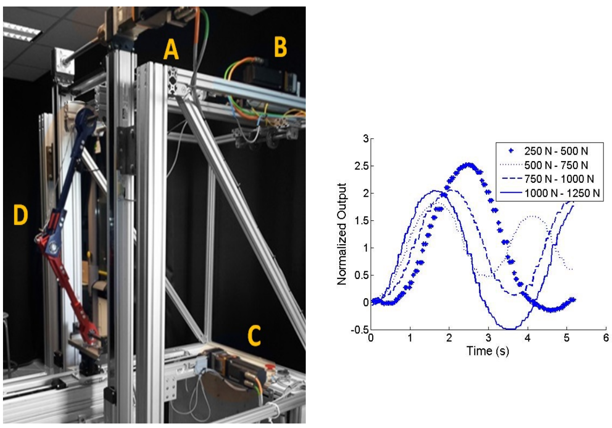

Figure 1: Left: Dynamic knee rig with 3 linear actuators (A,B and C) and a mechanical knee (D). Right: Capturing the system's nonlinear dynamics.

The system has an nonlinear oscillatory behavior which can be seen in the right part of figure 1. A step of 250 N has been applied in each range of the quadriceps force and the normalized force output has been plotted.

3 Controller design and results

In order to improve control of the quadriceps force, the x-position of the ankle and the y-position of the ankle in the system, two PD controllers have been designed based on specifications such as settling time and overshoot. In a first step the PD controller for the x-position and the y-position have been taken the same with a K_p value of 1 and a T_d value of 0,05. The resulting PD controller for the quadriceps force has a K_p value of 1 and a T_d value of 0,02. In figure 2 we can see an experiment where the quadriceps force is gradually increased in steps while maintaining a constant x- and y-position for the ankle. The newly designed controller is compared to the original situation in order to visualize the enhancement.

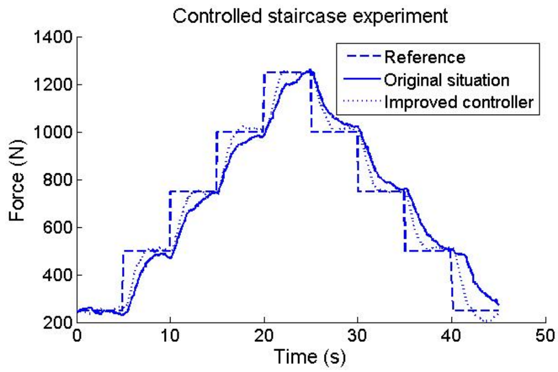

Figure 2: Closed loop control.

4 Conclusion

Initial work for controller design in a dynamic knee rig is presented in order to obtain implementation of natural movements on a knee prosthesis.

References

[1] M. R. Pitkin, "Biomechanics of Lower Limb Prosthetics" Springer, 2010.